HERBIVORY OF FERAL GOATS ON ESPIRITU SANTO ISLAND, GULF OF CALIFORNIA, MEXICO

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ABSTRACT

Islands are fragile ecosystems, and are especially sensitive to introduced species, particularly large herbivores. In Mexico, there are some dramatic cases. We evaluated the influence of feral goats, as well as the natives black jackrabbit and desert woodrat on the vegetation of Espiritu Santo Island, a land-bridge island in the southern part of the Baja California Peninsula. We found that goats consumed 36 vascular plant species, three times more species than natives jackrabbits and almost seven times more than woodrats. Also, goats consume all plant organs except roots, but reiterate browsing gradually affect vegetative and reproductive plant fitness. Our results support plans for the eradication of goats to spontaneously and progressively restore of the natural vegetation structure and composition. Further, a monitoring plan is recommended.

KEY WORDS: goat herbivory, *Capra hirca* eradication, goat eradication, Baja California Islands

RESUMEN

Las islas son consideradas ecosistemas muy frágiles. Estas son sensibles a la introducción de especies exóticas, particularmente herbívoros mayores. En México existen casos dramáticos. En este trabajo se evalúa el efecto sobre la vegetación en complejo insular Espíritu Santo, Baja California Sur, México, de las cabras silvestres contra el causado por las especies nativas, la liebre negra y la rata de campo. Las cabras consumen 36 especies de plantas vasculares, tres veces más especies que las liebres y casi 7 veces más que las ratas. También, se encontró que las cabras consumen todo tipo de órganos vegetales excepto raíces, pero el ramoneo reiterado afecta tanto la aptitud vegetativa y reproductiva de los vegetales. Los resultados apoyan el plan de erradicación de las cabras con la finalidad de que espontánea y progresivamente se restaure la vegetación en estructura y composición. Adicionalmente se requiere de un plan de monitoreo.

INTRODUCTION

Extinction and extirpation of native plants and animals from islands are significantly correlated with the introduction of exotic grazing mammals. Prevention of introduction and establishment of exotics on islands is vital, so that a program of eradication or control of existing exotics is required on many islands around the world, and eradication of new introductions, as soon after detection as possible, should be a high priority for conservation agencies and natural areas administrators by means of early detection and rapid response (McChesney & Tershy 1988; Burbidge 1999; Donlan et al. 2002).

Feral domestic goats (*Capra hircus* L.) are implicated in habitat destruction and alteration of species composition in sensitive insular ecosystems around the world (Scowcroft & Hobdy 1987; Jennings 1987; Parkes 1990). In the absence of population controls, goats become the ecologically dominant species on many islands, with the result that numerous native and endemic plant species have been extirpated or are threatened with extinction (Coblentz 1978; Keegan et al. 1994). A dramatic case is Isla Guadalupe in the Pacific Ocean near the state of Baja California, Mexico. This island was devastated by

grazing goats and erosion caused by soil trampling, to the extent that some native species and entire plant communities have vanished (León de la Luz et al. 2003; Oberbauer 2006).

Espiritu Santo is a small archipelago of two major land bridge islands and several islets in the southwestern Gulf of California (Fig. 1). They are included in the Gulf of California island protection program covered by Mexican environmental laws, and administered by the Natural Protected Areas Commission (CONANP). The largest island is Isla Espiritu Santo is separated on the north by a 10 m wide channel from the second island, Isla Partida Sur. Additionally, there are the islets of La Ballena, El Gallo, La Gallina, and Los Islotes (Fig. 1).

An undetermined number of domestic goats were introduced to Isla Espiritu Santo around the middle of the 20th Century to serve as a supply of fresh meat for local fishermen. Currently, there are hundreds of feral goats on the island that are gradually destroying the vegetation, eventually leading to extinction of native species. An informal animal census by the authors in spring 2001 provided an estimate of 1,000 to 1,200 goats occupying Isla Espiritu Santo. Field observers could not be more precise because the general relief, escarpments, and steep slopes made conventional counting methods impossible.

Because these islands are narrow and rocky, runoff is very rapid after the relatively rare rains. With little percolation into the soil, water is collects in occasional drainage pools. Thus, plants on the islands seem to have more profound water stress than on the main peninsula, a condition that is reflected by poor reproductive response, including less blooming, setting of fruit, and seed production than populations of the same species on the peninsula (author, pers. obs.). These conditions critically reduce the recovery capacity of the plant community, and consequently, the dependent animal guilds.

One of the greatest challenges for administrators of protected areas is maintaining biodiversity of native species and habitat loss. In Mexico, most of the islands have been protected to keep their biodiversity. This island, which is federal property and a protected area, is being considered for a program of goat eradication by the administrators (SEMARNAT, Baja California Sur). The administrators are familiar with the catastrophic effects of grazing activity on islands around the world and in Mexico.
Based on field transects, this study compared and evaluated differential consumption of plants by feral goats and the endemic black jackrabbit (*Lepus insularis* Bryant) and desert woodrat (*Neotoma lepida* Thomas subsp. *vicina* Goldman) on Isla Espiritu Santo, comparing their impacts on the vegetation. Following goat eradication, our data could provide support for prediction of the recovery of the plant community.

METHODS

Site description

The Espiritu Santo archipelago (24°24' to 24°36' N, 110°18' to 110°27' W) is part of the state of Baja California Sur. The nearest approach to the coast of the Baja California Peninsula is barely 8 km, northwest of the port at Pichilingue. The longest axis of the archipelago (NW-SE) is 19 km; the widest reach (E-W) is about 3.5 km. The archipelago covers 110 km^2, 87 km^2 on Isla Espiritu Santo and 20 km^2 on Isla Partida. The highest point, near the midpoint of the big island is 540 m (Fig. 1).

Geologically, the archipelago is composed of sedimentary rocks of volcanic origins (sandstones and conglomerates) of the Comondu Formation. Variations in resistance to weathering lead to a rugged topography. Except in a few areas, most of the surface has

Fig. 1. Geographical location of the study area in northwestern Mexico, at the Gulf of California insular system. Isolines indicate areas over 200 m. Cross (†) indicates the highest point in the island (540 m).

very steep rocky slopes where some soil is present beneath rocks. The uplands are tablelands where goats concentrate at nights. The west side of the island is highly dissected by ravines descending from the uplands to sea level. On the shore, salt flats form behind mangrove stands and sandy pocket beaches at the end of coves. The east side of the island is largely wave-cut cliffs and pebble beaches.

Weather data are not available for the island, but an approximation, based on records from the city of La Paz, suggests annual mean rainfall <170 mm and potential evaporation of 2500 mm. Rainfall is erratic, with fall-winter-spring of 8 to 10 months without any rainfall. Occasional hurricanes in the late summer could drop up to three times the annual mean.

Vegetation is typical of the peninsular Sonoran Desert, the sarcocaulescent scrubland (Shreve & Wiggins 1964) is characterized by perennials with semi-succulent stems, including cacti and deciduous woody shrubs. According to the last inventory, 254 taxa are found (Rebman et al. 2002). Families include Compositae (28 taxa), Leguminosae (25), Euphorbiaceae (24), Graminae (20), and Cactaceae (15), these five totaling 44% of all the taxa. Some of the commonest arborescent forms physiognomically dominating the slopes are: "palo blanco" *Lysiloma candida* Brandegee, "salate" *Ficus petiolaris* HBK subsp. *palmeri* S. Wats., "cacachila" *Karwinskia humboldtiana* (Roem. & Sch.) Zucc., and "cardón" *Pachycereus pringlei* (S. Wats.) Britt. & Rose.

Constant and strong winds noticeably contribute to lignosity in branches and a more

dwarflike appearance than examples of the same species growing on the Baja California Peninsula. With a north-south mountain ridge axis, the canyons run east and west, and the isolation generates different exposure-based plant associations on north-facing (shadow-side) and south-facing (sun-side) slopes. North-facing slopes having significantly more canopy and plant density than the intensely exposed south-facing slopes. Surveys by the author, based on 400 m^2 sampling plots, provide plant canopies averaging 220 m^2 on south-facing slopes and 305 m^2 on north-facing slopes, on opposite sides of the same ravine (author, unpublished data).

Sampling

In March 2001, ten straight-line transects of approximately 3 km each, were designed so that each would traverse several environments. Transects included beaches and mangrove (one site), arroyos and washes (three sites), slopes (four sites), and tablelands (two sites). Information recorded included: 1) plant and organs consumed or injured, 2) evidence for the responsible herbivorous species, based on characteristics of common sense, including type of bite on the plant and supporting evidence of droppings (pellets) beside the damaged plants. Droppings of goats are barrel form, approx. 1 cm long; those of jackrabbits are elliptic-lenticular form, approx. 1 cm long, and those of desert woodrats are linear, approx. 1 cm long.

Because the three herbivores typically defecate next to the browsed plant during feeding, we considered such occurrences related and definitive. Figure 2 shows a foraged plant and pellets of goats and black jackrabbits. Intensity of feeding activity was determined by the number of old scars on plants and the abundance and age of pellets around these plants.

RESULTS

Table 1 assembles the information by sampled sectors, showing elevation, browsed species, consumed or injured plant organs, evidence of the herbivore species, and intensity of consumption based on scat abundance. From the transect surveys, we found that browsing by goats was concentrated on the more elevated mountains of the island near La Ballena and Los Candeleros Coves, and on uplands above 400 m.

Discussion

In general terms, abundance and distribution of plants on the island is definitely dependent on terrain conditions, such as slope angle and exposure, as well as soil quality (soil deep and rockiness). These factors contribute to vegetation heterogeneity on the landscape. We believe that many native plant species have been modified by goat browsing over the past several decades, knowing that goat herbivory directly affects fitness and reproductive success of mature plants and also contributes to consumption of juvenile plants. Donlan et al. (2002) documented positively changes in plant coverage on several Gulf of California islands after extirpation of exotic herbivores.

Some actively browsed plant species are the perennial herbs *Bebbia juncea* (Benth.) Greene, *Justicia californica* (Benth.) Gibson, and *Ditaxis lanceolata* (Benth.) Pax & K. Hoffm. and the sub-shrubby *Aeschynomene nivea* Brandegee. We found that browsing of terminal branches promotes sprouting from basal nodes, leading to a branching architecture of unusually short basal trunks and numerous branches. Several individual "palo blanco" *Lysiloma candida*, one of the few tree-like species, had trunks stripped of the high-tannin bark, as well as shrubby species of "lomboi" *Jatropha cinerea* (Ortega) Muell.-Arg.

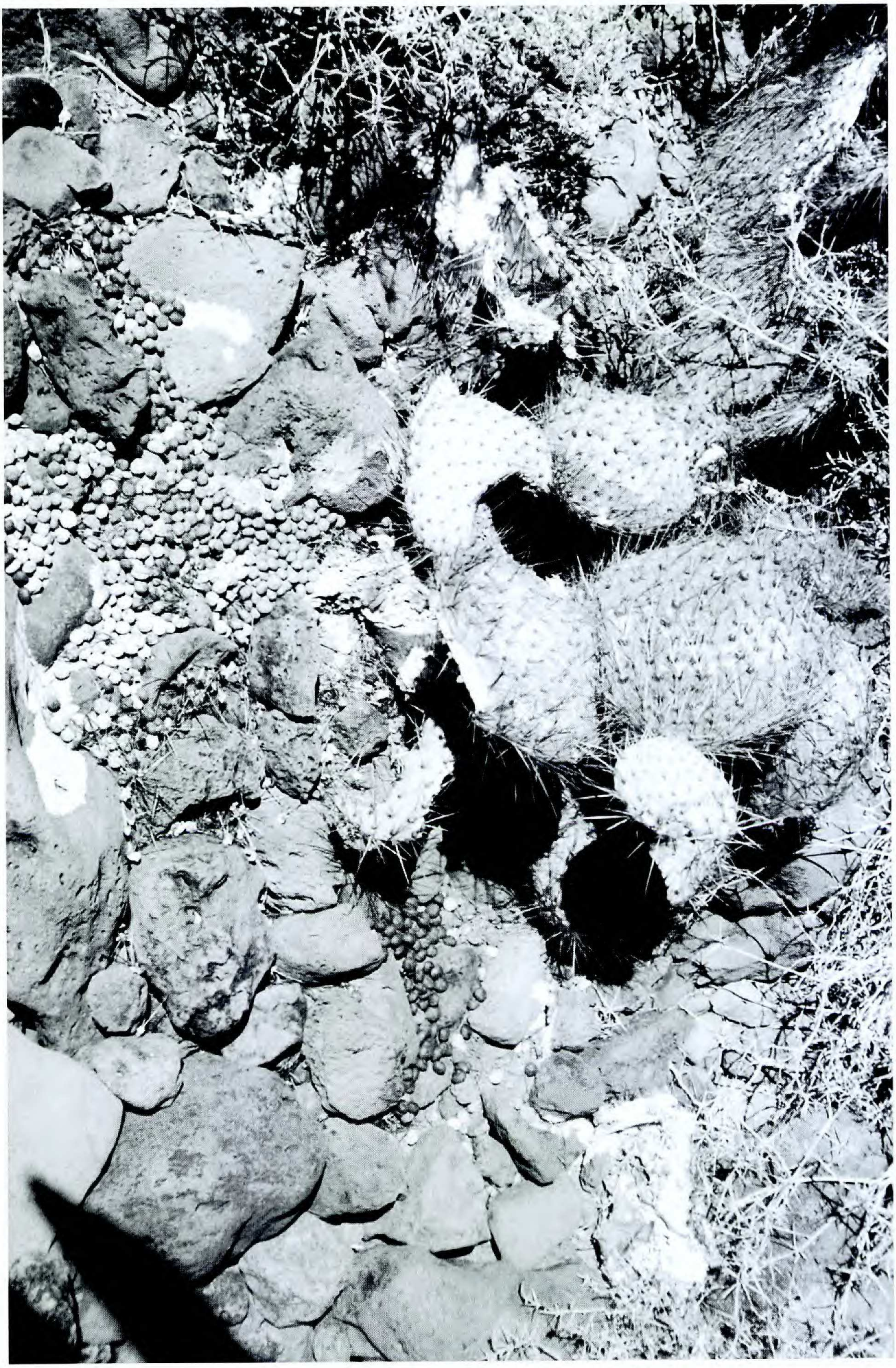

FIG. 2. Clades of *Opuntia tapona* showing damage. Note goat and jackrabbit pellets on ground.

TABLE 1. Perennial plant species affected by herbivory of feral goats, black jack-rabbits (BJR), and wood rats on Isla Espiritu Santo, Baja California Sur, Mexico, based in ten 3-km transects during a field survey in spring 2001.

Plant species (asl)	Consumed organ	Herbivore	Intensity
Beaches and mangrove (0–2 m)			
Rhizophora mangle L.	Leaves, Bark	Goat	Low
Avicenia germinans (L.) L.	Leaves, Bark	Goat	Low
Monantochloe littoralis Engelm.	Leaves	BJR	Low
Jouvea pilosa (Presl.) Scribn.	Leaves	Goat	Low
Arroyos and washes (5–15 m)			
Viscainoa geniculata (Kell.) Greene	Leaves	Goat	Low
Forchammeria watsonii Rose	Leaves	Goat	Low
Euphorbia magdalenae (Benth.) Millsp.	Buds	Goat	Low
Lysiloma candida Brandegee	Flowers, Leaves, Bark	Goat	Low
Melochia tomentosa L.	Buds	Goat	Low
Stenocereus gummosus (Engelm.) Gibson & Horak	Stems	BJR, Rat	Low
Pachycereus pringlei (S. Wats.) Britt. & Rose	Flower, Bark	Goat, BJR	Low
Simmondsia chinensis (Link) Sch.	Leaves	Goat	Low
Colubrina viridis M. E. Jones	Bark	Goat	Low
Bebbia juncea (Benth.) Greene	Leaves	Goat	Low
Cochemia poselgeri (Hildmann) Britt. & Rose	Stems	BJR, Rat	High
Prosopis articulata S. Wats.	Stems, Leaves	Goat, BJR	Medium
Slopes (10–150 m)			
Justicia californica (Benth.) Gibson	Stems, Leaves, Buds	Goat	High
Ditaxis lanceolata (Benth.) Pax & K. Hoffm.	Stems, Leaves	Goat	High
Desmanthus fruticosus Rose	Stems, Leaves	Goat	High
Aeschynomene nivea Brandegee	Stems, Leaves	Goat	High
Agave sobria Brandegee var. *roseana* (Trel.) Gentry	Flowers	Goat	High
Acacia pacensis Rudd & Carter	Buds	Goat	High
Heteropogon contortus (L.) Beauv. ex Roem.	Leaves	Goat	Medium
Cylindropuntia cholla Weber	Flowers, Fruit	BJR, Rat	Low
Macrosiphonia hesperia I. M. Jhtn.	Stems, Leaves	Goat	High
Ficus petiolaris subsp. *palmeri* S. Wats.	Leaves, Buds	Goat	High
Bouteloua reflexa Swallen	Leaves	Goat	Medium
Solanum hindsianum Benth.	Buds	Goat	Medium
Tableland (150–450 m)			
Acacia pacensis Rudd & Carter	Stems	Goat, BJR	Medium
Agave sobria Brandegee var. *roseana* (Trel.) Gentry	Flowers, Leaves	Goat	Medium
Bursera epinnata (Rose) Engler	Buds	Goat	Medium
Caesalpinia placida Brandegee	Stems, Leaves	Goat	Medium
Parkinsonia florida Benth. ex A. Gray subsp. *peninsulae* (Rose) Carter	Stems, Leaves, Buds	Goat	Medium
Fouquieria burragei Rose	Buds	Goat	Medium
Jatropha cinerea (Ortega) Muell.-Arg.	Buds	Goat	Occasional
Lysiloma candida Brandegee	Bark	Goat	Medium
Olneya tesota A. Gray	Buds	Goat	Medium
Opuntia tapona Engelm.	Stems	Goat, BJR	Medium
Simmondsia chinensis (Link) Sch.	Stem, Leaves	Goat	Medium
Euphorbia magdalenae (Benth.) Millsp.	Buds	Goat	Occasional
Euphorbia tomentulosa (S. Wats.) Millsp.	Buds	Goat	Occasional
Xylothamia diffusa (Benth.) G.L. Nesom	Stems, Leaves	Goat, BJR	Occasional

TABLE 1. continued

Plant species (asl)	Consumed organ	Herbivore	Intensity
Tableland (150–450 m) (cont.)			
Stenocereus gummosus (Engelm.) Gibson & Horak	Stems	BJR	High
Maytenus phyllanthoides Benth.	Stems	BJR, Rat	Low
Pedilanthus macrocarpus Benth.	Stems	BJR	Occasional
Opuntia cholla Weber	Stems	Goat, BJR	Medium
Hyptis laniflora Benth.	Buds	Goat, BJR	Medium
Pachycereus pringlei (S. Wats.) Britt. & Rose	Stems	Goat, BJR	Occasional
Echinocereus brandegeei (Coult.) K. Schum.	Stems	Rat	Medium

(see Fig 3). Some plants of "cardón" *Pachycereus pringlei*, a large columnar-arborescent cacti, have old scars on their trunks (>20–40 cm above the ground), evidence of browsing by goats and probably also jack-rabbits during periods of severe drought. Our observations suggest that only two species of "choya" cacti (*Cylindropuntia cholla* Weber and *C. alcahes* Weber) could benefit from goat browsing because sexual reproduction in these two species is very limited and their jointed stems separate easily, adhere to goat hair, and are easily dispersed and eventually they could settling by vegetative processes.

Black jackrabbits and desert wood rats have a significantly lower impact on the vegetation because, as smaller browsers; individually they consume less plant material and their population biomass seems to be less than the hundreds of goats.

From the data assembled in Tables 1 and 2, we found that the most intense location of browsing by goats is on stems and, at least during spring, is frequent and intense. This browsing habit almost entirely consumes the floral and leaf shoots, the juicy and less woody tissues of the plants. After the rainy season, the goats concentrate on browsing the newly emerging foliage.

The evidence indicates that a set of plant species display consumption of or injury to the meristematic apex of the branches, that is, the fresh and fluid-filled tissues, rather than woody tissue and stem bark. Clades of *Opuntia tapona* Engelm. are specially consumed by all the animals because the high water content. With freshwater in very short supply and stored in "tinajas" after rainfall, goats manage to prosper by drinking salty water (Burke 1990). During our field work, we observed a few goats drinking seawater at the beach at sunset, which suggests daily or close to daily migration from the uplands to the shore. At the shore, goats also consume halophytic plants, including mangrove and species of salt grasses.

Our findings demonstrated that goats are the most significant herbivores, capable of consuming almost all plant parts. While the native black jackrabbit and desert woodrat have the same feeding habits as goats and inhabited the island for millennia, their density and biomass have far less impact on the vegetation.

Finally, there was no direct evidence that goats consume an entire plant; however, high intensity herbivory strongly affects the fitness of each grazed plant, and can eventually lead its death. We conclude that the natural balance of vegetation on Isla Espiritu Santo is deleteriously affected by goat herbivory, which combined with the impact of the native foragers, increases the deleterious effects of browsing on a large group of plant species. Our data supports plans for the total eradication of goats from the archipelago.

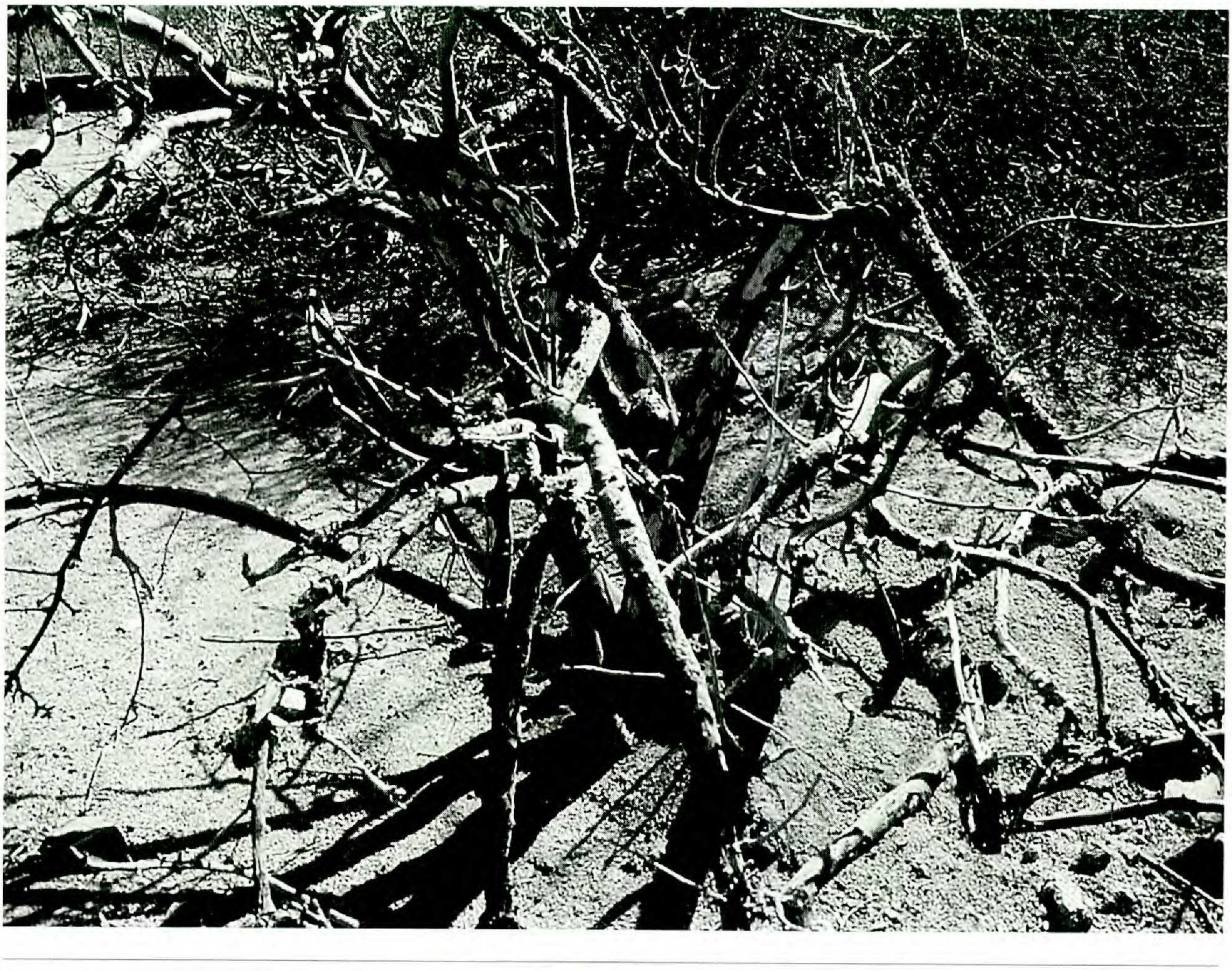

Fig. 3. An exemplar of *Jatropha cinerea* showing damage by goats, note bark stripping and broken branches.

Table 2. Concentrated data of plants consumed by herbivores on Isla Espíritu Santo, Gulf of California, Mexico.

Herbivore	Plant species consumed	Plant organs consumed	Sector of activity
Goats	36	Flowers, buds, leaves, young stems, bark	Slopes, high tablelands
Jackrabbits	13	Stems	Arroyos, high tablelands
Woodrats	5	Stems, fruit	Arroyos, slopes

On an ecological basis, black jackrabbit and woodrats are foragers that control the vegetation growth.

After eradication a monitoring plan is strongly recommended. We hope that the same plants indicated in Table 1 will increase their density and size. In fact, eradication of goats is currently underway by the administrators of the island. The project is expected to be completed by winter 2006/07, with only radio-collared and sterile sentinel goats remaining (Donlan et al. 2002).

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